Contract Number DACA42-03-C-0001

ReliOn

FAA Radio Transmit Receive Site Backup Power Demonstration Final Report

Proton Exchange Membrane (PEM) Fuel Cell Demonstration Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers Engineer Research and Development Center Construction Engineering Research Laboratory Broad Agency Announcement CERL-BAA-FY02

McChord Air Force Base, Washington

June 11, 2004

ReliOn PEM Fuel Cell Backup Power Demonstration Final Report

Executive Summary

On January 14, 2003, ReliOn, then named Avista Labs, installed a 3 kW fuel cell system consisting of six, Independence 500™ fuel cells at McChord Air Force Base in Tacoma, WA. The backup power fuel cell system was located at a Radio Transmit Receive (RTR) site owned and operated by the U.S. Federal Aviation Administration (FAA). Funding for this project was obtained from the Construction Engineering Research Lab, a division of the U.S. Army Engineer Research and Development Center (ERDC). The purpose of the demonstration was to provide reliability data to both the FAA and ERDC to support commercial purchases and installations of the ReliOn Independence fuel cell systems.

The formal commissioning ceremony occurred on April 17, 2003, at which point the one year test program commenced. The six Independence 500™ fuel cells were connected in parallel to the FAA's RTR battery system. These batteries serve as a source of backup power in the event of AC power loss. In this configuration, the fuel cells can significantly extend the backup power run time if called upon. The ultimate run time is limited only by the hydrogen fuel replenishment beyond the nominal 48 kWh storage capacity in the system. The test program was structured in two phases. Phase 1 was scheduled for the first six months of the program, during which the control system simulated a 20 minute loss of AC power three times each day for seven days a week. The fuel cell system automatic start sequence was initiated at the start of each loss of AC power test. For the Phase 1 test runs, the fuel cell power was dissipated in a resistive load bank. Phase 2 took place during the final six months of the program and added a 2 hour grid power failure simulation every Sunday to the daily tests. For this weekly test, the load bank was disconnected and the fuel cells carried the full RTR load while maintaining charge voltage to the facility battery system for the 2 hour period.

The one year test program was completed on Friday, April 17, 2004 and test operations were curtailed on April 19. Through the end of the operating period, the system was monitored for over 8800 hours and accumulated over 1100 successful starts for a total fuel cell run time of 418.9 hours. Total system reliability for the entire test program was 99.4%, reduced only by a faulty hydrogen safety detector, an auxiliary heater failure, and a problem with the onsite laptop computer. This installation and demonstration illustrates the viability of utilizing ReliOn hydrogen-fueled PEM fuel cell systems to supplement and/or replace large lead acid battery systems.

APPENDIX 2 – MAINTENANCE LOGS

Table of Contents

EXECU	TIVE SUMMARY	i
1.0	DESCRIPTIVE TITLE	1
2.0	NAME, ADDRESS AND RELATED COMPANY INFORMATION	1
3.0	PRODUCTION CAPABILITY OF THE MANUFACTURER	1
4.0	PRINCIPAL INVESTIGATORS	2
5.0	AUTHORIZED NEGOTIATOR	2
6.0	PAST RELEVANT PERFORMANCE INFORMATION	3
7.0	HOST FACILITY INFORMATION	5
8.0	FUEL CELL INSTALLATION	6
9.0	ELECTRICAL SYSTEM	8
10.0	THERMAL RECOVERY SYSTEM	9
11.0	DATA ACQUISITION SYSTEM	9
12.0	FUEL SUPPLY SYSTEM	10
13.0	FUEL CELL TEST PROGRAM	11
14.0	PROGRAM COSTS	13
15.0	MILESTONES/IMPROVEMENTS	14
16.0	DECOMMISSIONING/REMOVAL/SITE RESTORATION	16
17.0	ADDITIONAL RESEARCH/ANALYSIS	17
18.0	CONCLUSIONS/SUMMARY	19
APPEN	DIX 1 – MONTHLY PERFORMANCE DATA	

1.0 <u>Descriptive Title</u>

Demonstration of ReliOn Proton Exchange Membrane (PEM) fuel cells as a backup power system for FAA Radio Transmit Receive communication systems, McChord Air Force Base, Tacoma, Washington.

2.0 Name, Address and Related Company Information

Name: ReliOn

Address: 15913 E. Euclid Ave., Spokane, Washington 99216

Phone: 509-228-6500 DUNS: 137264193 CAGE: 1G8G7 Federal ID: 91-2191190

ReliOn (formerly Avista Labs) is the leading provider of high reliability fuel cell solutions for backup power applications. The company markets a variety of commercially available Proton Exchange Membrane (PEM) fuel cells using its patented Modular Cartridge Technology.

3.0 <u>Production Capability of the Manufacturer</u>

ReliOn is located in Spokane, Washington and is a provider of commercially available PEM fuel cell systems. Current production consists of Independence 1000™ fuel cell modules and outdoor enclosure systems. These products are manufactured and shipped to industrial, government, and international customers under full commercial warranty programs.

All fuel cell systems are assembled at the Spokane, Washington facility. The current facility has the capability to produce 10 fuel cell systems per week, running one shift and without contract labor. This capacity can easily be expanded with the addition of contract labor and back shifts. If demand exceeds this capacity, the production lines could be duplicated at contract manufacturers. At least three contract manufacturers are available locally which could quadruple the capacity. In addition, large national contract manufacturing firms have been identified to further increase production for even higher demand.

ReliOn fuel cells are made from common materials using mature manufacturing processes in injection-molded plastic, sheet metal fabrication and printed circuit board assembly. The PEM membrane electrode assemblies are purchased through supply agreements with established manufactures. Minor capital expenditures are required to expand production.

ReliOn PEM Fuel Cell Backup Power Demonstration Final Report

4.0 <u>Principal Investigators</u>

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5.0 <u>Authorized Negotiator</u>

Name Frank Ignazzitto

Title Vice President, Sales- Government & West

Company ReliOn

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Email <u>fignazzitto@relion-inc.com</u>

6.0 Past Relevant Performance Information

Modular 2 kVA Fuel Cell Power Plant with Live Replaceable, Self-Hydrating PEM Smart Cartridges

On November 1, 1998, ReliOn, then named Avista Labs, was awarded a \$1,999,786 grant from the Advanced Technology Program of the National Institute of Standards and Technology to further development its novel modular fuel cell power plant design. The project resulted in the successful development, demonstration, and commercial production of modular fuel cell systems with hot-swappable, self-hydrating PEM cartridges. Since the completion of this project, the basic modular fuel cell design has undergone further improvement and now forms the basis of ReliOn's fuel cell product line ranging from 1 kW to 5 kW. Another result of this program was the development of a methanol fuel reformer to produce a hydrogen-rich gas stream for use in the fuel cell systems. Operation of ReliOn cartridges and the fuel cell module was successfully demonstrated in the program.

Company: U.S. Department of Commerce, National Institute of Standards and

Technology, Advanced Technology Program

Contract Number: 70NANB844069

Dollar Value: ATP Cost Share - \$1,999,786

Avista Labs (ReliOn) Share - \$485,400 Total Project Value - \$2,485,186

Contact: Jean-Louis Staudenmann
Title: Technical Project Manager

Phone: (301) 975-5346

Date Awarded: 1 November, 1998

- 242nd Combat Communications Squadron; Geiger Field, WA, Building 401

On March 29, 2002, ReliOn, then named Avista Labs, commissioned a 3kW, SR-72 fuel cell system with funding from the Construction Engineering Research Lab, a division of the U.S. Army Engineer Research and Development Center (ERDC). The purpose of the installation was to demonstrate the viability of PEM fuel cell systems as a reliable source of power to various Department of Defense installations. Additionally, this installation would provide long-term test data of Avista Labs' unique, modular PEM fuel cell system. A major project deliverable dictated the fuel cell provide over 90% availability to its specific customer loads. Specific loads powered included building lighting, building bay doors, and the building Local Area Network (LAN) switch. The system was operational for one year commencing on March 29, 2002 and maintained an uptime of 92.87%.

Company: U.S. Army Corp of Engineers, Construction Engineering Research

Laboratory

Contract Number: DACA42-02-C-0002

Dollar Value: \$184,300 Contact: Dr. Mike Binder Title: Program Manager Phone: (217) 373-7214

E-mail: m-binder@cecer.army.mil

Project Capacity: 3 kW

Date Installed: 29 March 2002

- SGS Future Installation; Cavalese, Italy

In November 2002, ReliOn, then named Avista Labs, completed the commercial sale of 13 Independence 1000 fuel cell systems to SGS Future, one of our distribution partners. Ten of these systems were installed in a parallel configuration providing 10kW of power for an installation near Cavalese, Italy. The fuel cells provide power to a mountaintop alpine lodge. Backpackers utilize the lodge, and it was desirable to employ an environmentally clean, quiet, reliable power source. The system has been installed and was operating at the end of 2002. The system was restarted in the spring of 2003. The dollar value below reflects only the cost of the fuel cells. Installation and enclosure costs were paid to a third party contractor by the customer, and not disclosed to Avista Labs.

Company: SGS Future

Contract Number: N/A
Dollar Value \$101,226

Contact: Dr. Andrea Tomasi
Title: Project Manager
Phone: +39 (046) 131-4489

E-mail: <u>tomasi@itc.it</u>

Project Capacity: 10 kW

Date Installed: 15 November 2002

- Independence™ Fuel Cell Shipments

As of April 2004, ReliOn has shipped a total of 174 PEM fuel cells to customers. Of this total, 86 systems are of the current Independence 1000[™] design. This model has been delivered to customers in the following categories:

Universities & Schools 11
Evaluation Testing Agencies 3
Government Applications 25
Other Applications 29
Utility Industry 5
Telecom 3
TOTAL 86

ReliOn PEM Fuel Cell Backup Power Demonstration Final Report

7.0 <u>Host Facility Information</u>

McChord AFB

Don Legg

Phone: (253) 982-2754

Email: don.legg@mcchord.af.mil

<u>FAA</u>

Ernie Sica

Phone: (425) 227-2266 Email: <u>Ernest.Sica@FAA.GOV</u>

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Phone: (253) 804-2954

Email: <u>Bob.Mcgranahan@FAA.gov</u>

Dave Powers

Phone: (425) 227-1552

Email: <u>Dave.Powers@FAA.GOV</u>

8.0 Fuel Cell Installation

Figure 1 shows plan view layout of the fuel cell enclosure with integrated hydrogen fuel supply. Photographs of the installation are shown in Figure 2. The outdoor enclosure was located at a distance of 40 feet from the east side of Building 1505 on Outer Drive, McChord Air Force Base, Tacoma, Washington. Building 1505 houses the FAA Radio Transmit Receive (RTR) equipment. The load bank used for Phase 1 simulated load testing was positioned on the east side of the building on a concrete pad. Three conduits extend from the building to the enclosure pad. The conduits carried AC power to the fuel cell enclosure, DC power from the fuel cell enclosure to the load bank and the RTR equipment in the building, control circuits wiring and telephone cables used for data logging and alert notification. A 2/0 AWG ground cable was connected between the facility ground system and the fuel cell enclosure. The composite concrete pad was placed on a bed of compacted gravel. The outdoor enclosure was bolted to the composite concrete pad. Concrete filled bollards were placed around the outdoor enclosure to prevent damage from vehicles. An AC disconnect, DC disconnect and Telephone/Control cable junction box were placed on a distribution back plane near the east side of Bldg. 1505. Two junction boxes were placed on a distribution back plane near the load bank pad for solid state relays and DC connection contactors.

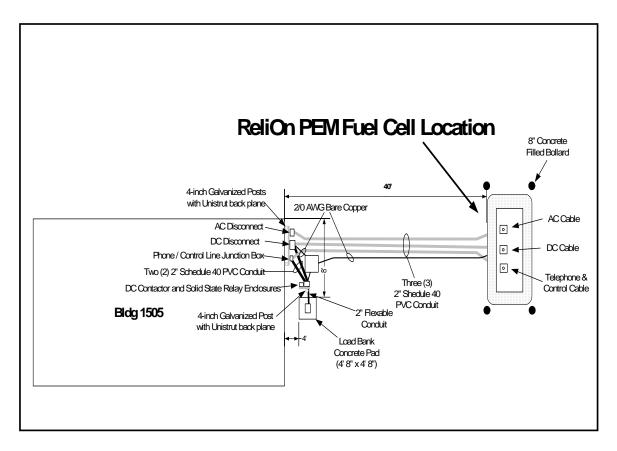
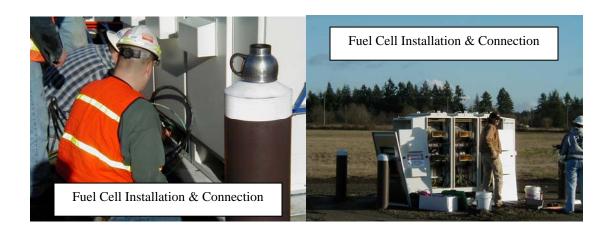


Figure 1. ReliOn PEM Fuel Cell Backup Power System Layout





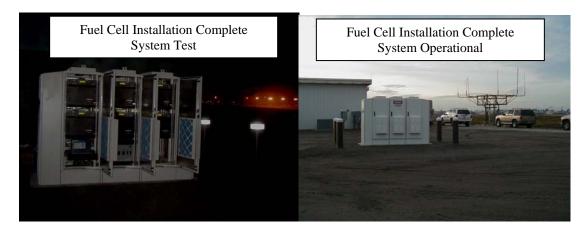


Figure 2. ReliOn PEM Fuel Cell Backup Power Installation At McChord AFB, Tacoma, Washington

9.0 <u>Electrical System</u>

Figure 3 shows the electrical connection schematic for the fuel cell system. The fuel cells were connected to the internal battery bank through a 150 Amp circuit breaker. The output of the battery bank was then connected to the DC disconnect through another 150 Amp circuit breaker. DC Voltage and current sensors were placed on each side of the internal battery bank to capture the voltage and current out of the fuel cells and the voltage and current out of the system to the load.

The DC disconnect was connected to two contactors that were controlled by a Programmable Logic Controller (PLC 2) located in the control enclosure in the ventilation room of Bldg. 1505. The contactor connecting the fuel cell system to the load bank was normally energized. The contactor connecting the fuel cell system to the FAA battery bank and DC bus was normally deenergized. Another Programmable Logic Controller (PLC 1) in the fuel cell enclosure controlled solid state relays that connected the 1 kW resistive load resisters in the load bank.

During Phase 2 of the system test (described in Section 13), the normally energized contactor was de-energized and the normally de-energized contactor was energized by PLC 2, allowing the fuel cell system to be connected to the FAA DC bus. A blocking diode was used to prevent the FAA DC bus from back feeding the fuel cell system battery bank. A normally closed relay was utilized to simulate power loss to the FAA 24 VDC rectifier. During the simulated power outage the relay opened to remove the AC grid power from the rectifier.

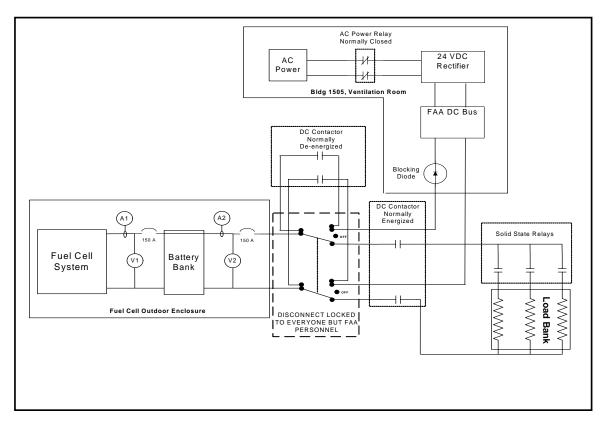


Figure 3. ReliOn PEM Fuel Cell Backup Power Connection To FAA DC Bus And 3 kW Resistive Load Bank

10.0 Thermal Recovery System

Not Applicable

11.0 <u>Data Acquisition System</u>

The data acquisition system is detailed in Figure 4. A data collection unit was connected to various sensors in the fuel cell enclosure. The data collection unit and the fuel cells were each connected to the data-logging computer though an Ethernet hub. The data-logging computer recorded total operating hours of the fuel cells, kilowatt hours produced, fuel consumption, maintenance logs, fuel cell system availability, outages and operating temperature. Additionally, internal and external temperatures and humidities were recorded. The data from the data-logging computer was downloaded to a server located at ReliOn by remote dialup after each scheduled system run. The data-logging computer also recorded alarms for the following conditions: AC power loss, H2 sensor alarm, low power output during test run, system voltage below 24 VDC, fuel cell cartridge off-line and fuel cell shutdown. The data-logging computer alarm notification utility dialed pre-programmed telephone numbers to alert ReliOn of any alarm condition.

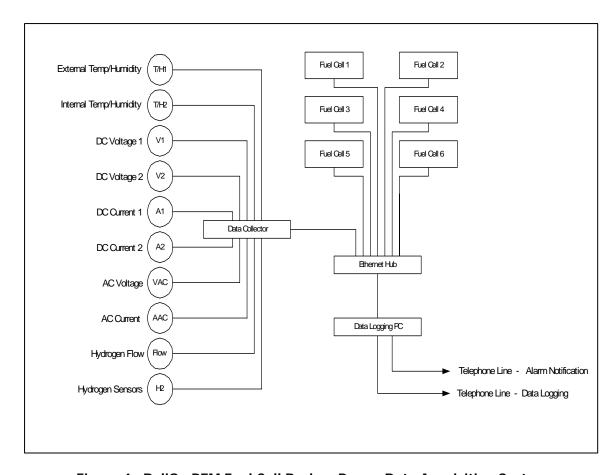


Figure 4. ReliOn PEM Fuel Cell Backup Power Data Acquisition System

12.0 Fuel Supply System

The hydrogen storage and supply system is illustrated in Figure 5. The outdoor enclosure was designed with an integrated hydrogen storage and delivery system. Hydrogen cylinders were contained in cabinets on each side of the enclosure. Each cabinet accommodated three 261 cubic foot cylinders of hydrogen, with a total storage capacity of six cylinders. The hydrogen cylinders were secured in place with nylon straps. Each compartment contained a manifold assembly, pressure regulator, manual shutoff valve, and solenoid valve.

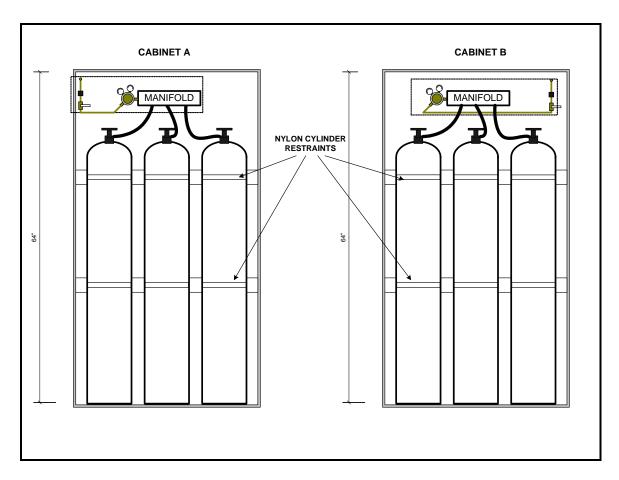


Figure 5. ReliOn PEM Fuel Cell Backup Power Fuel Supply System

The hydrogen supply piping and safety circuit is shown in Figure 6. The hydrogen was piped into the fuel cell cabinets of the enclosure using ¼-inch brass tubing. Prior to distribution to the fuel cells, a flow meter was connected in line to capture the flow rate of the hydrogen. Each fuel cell compartment contained a regulator to regulate the pressure to 5 PSI prior to connection to the fuel cells. The hydrogen bleed from each fuel cell compartment was exhausted though a vent tube on the roof of each compartment. Brushless DC exhaust fans evacuate each fuel cell cabinet for one minute prior to system start. Hydrogen sensors were located in each fuel cell cabinet. The hydrogen supply solenoids were normally closed and interlocked with the normally closed contacts of the sensors. If a leak was detected, the solenoids were de-energized causing them to close. The hydrogen sensor alarm was required to clear before the solenoids were re-

energized. A flow orifice limited the maximum possible flow of hydrogen to 2 cubic feet per minute.

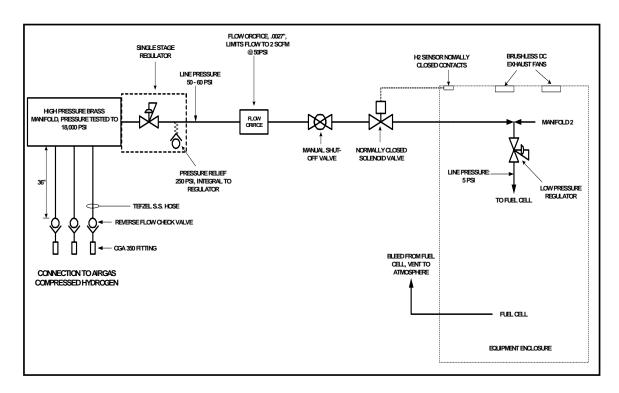


Figure 6. Hydrogen Supply Piping And Safety Circuit

13.0 Fuel Cell Test Program

Figure 7 depicts the system functional block diagram. The system was designed to simulate a typical DC powered system with battery backup. The outdoor enclosure housed the six Independence 500™ fuel cells along with a small internal battery bank, and rectifier. The rectifier and internal battery bank provided power to the PLC controller in the enclosure, data collection system, and data logging computer. AC power was connected to the enclosure to power the rectifier and maintain charge voltage to the internal battery bank when the fuel cells were offline between test periods. AC power was also utilized to power temperature controlled heaters to maintain the temperature inside the enclosure above 4°C (40°F). During the test periods, the PLC in the outdoor enclosure simulated an AC power outage by disconnecting AC from the rectifier and the heaters. At the same time the power outage was simulated, the fuel cell system automatic start sequence was initiated.

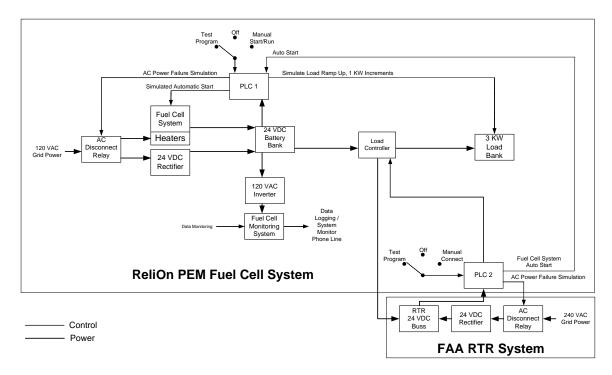


Figure 7. ReliOn PEM Fuel Cell Backup Power Functional Block Diagram

The test program was broken down into two phases:

Phase 1 – Load bank Testing

The first phase involved simulating a 20-minute loss of AC grid power and automatic startup of the fuel call system. A 3kW resistive load bank was then added in 1kW increments during the 20-minute test. The load was increased in 5-minute intervals with the first five minutes at 1 kW, the next five minutes at 2 kW and the final ten minutes at 3kW. The test was conducted three times a day, 7 days a week.

Phase 2 – Radio Transmit Receive (RTR) Site Power

The second phase was started on Sunday October 26, 2003. Phase 2 continued the load bank runs performed in Phase 1, and added a weekly test to provide power to the Federal Aviation Administration (FAA) Radio Transmit Receive (RTR) site for 2 hours every Sunday. The connection to the FAA RTR site involved a simulation of an AC grid power outage at the RTR site, automatic startup of the fuel cell system and automatic connection of the fuel cell system to the RTR site DC bus.

14.0 <u>Program Costs</u>

Table 1 shows a breakdown of project costs for the ReliOn PEM fuel cell backup power demonstration project. The total estimated cost in the proposal budget was \$139,973. The total award amount in the fixed-price contract was \$136,342. Total billed expenditures (including committed site restoration activities) through April 22, 2004 were \$136,342.

Table 1. Project Costs for Contract Number DACA42-03-C-0001

Category	roposed Budget	Award Amount	TI	ual Billed nrough l 22, 2005
Site Preparation & Installation				
Mechanical & Civil (Consisting of)	\$ 22,000			
3 Modular Enclosures for Independence 500s				
Concrete Composite Pad for Enclosure				
Truck Rental for Transport of Skid Mount Enclosure				
Electrical (Consisting of)	\$ 12,000			
Install 120 Volt AC Feeder to Enclosure				
Install 48 volt feeder with Disconnects to Customer Load				
Total Site Preparation & Installation:	\$ 34,000		\$	34,895
Fuel Cell & Fuel Storage/Distribution Total:	\$ 34,370		\$	28,253
Monitoring & Communications				
Date Extraction	\$ 9,000			
Date Storage	\$ 4,000			
Communication	\$ 2,000			
Total Monitoring & Communications:	\$ 15,000		\$	10,635
Labor	\$ 28,048		\$	38,738
Fuel Cost	\$ 7,055		\$	9,441
Travel	\$ 16,500		\$	7,546
Miscellaneous	Í			
Replacement or Upgraded Equipment (Consisting of)				
Revised bleed gas system				
Hydrogen sensors				
Total Miscellaneous:	\$ -		\$	1,834
Site Restoration (Not expended, but committed as of April 22, 2004)	\$ 5,000		\$	5,000

	Project Total:	\$ 139,973	\$ 136,342	\$ 136,342

The cost of industrial grade hydrogen fuel from the vendor was \$0.0675 per cubic foot. With handling, delivery charges and taxes, the effective cost of fuel delivered to the site was \$0.0858 per cubic foot (not including cylinder rental, charged at \$4.50 per cylinder per month).\(^1\) As detailed in Appendix 1, the net fuel cell system efficiency was 56.69% (LHV basis) for the demonstration project. With this system efficiency, the fuel cost rate as consumed was \$1.94 /kWh. These costs are illustrated in Figure 8.

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¹ In 2003 the fuel charges were \$0.156 per cubic foot, and \$0.199 per cubic foot as delivered. ReliOn negotiated a new supply agreement with the vendor which took effect on January 1, 2004.

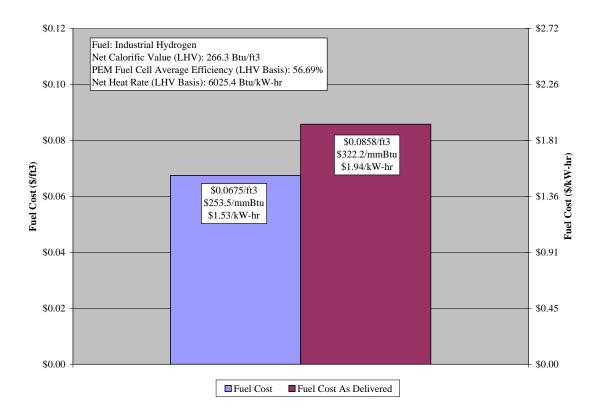


Figure 8. ReliOn PEM Fuel Cell Backup Power Demonstration Project Fuel Costs

15.0 <u>Milestones/Improvements</u>

The one-year test program was completed on Friday, April 17, 2004. The fuel cell systems were shut down following the 4 AM run on Monday, April 19, 2004. Through the end of the operating period on April 19, the total system run time was 418.9 hours, consisting of 410.9 hours of operation within the scheduled test periods, and additional run hours outside of the normally scheduled test periods. The scheduled test runs consisted of 359.6 hours of cumulative Phase 1 data, and 51.3 hours of cumulative Phase 2 data. See Attachment 1 for summaries of run data.

Total reliability (Actual Starts/Attempted Starts) for the entire test program was 99.4%. Total availability (Actual Run Time In Scheduled Period/Scheduled Run Time in Period) for the entire test program was 97.4%. The individual fuel cells were very reliable throughout the 1 year program, presenting an effective demonstration of ReliOn's modular, air cooled, self hydrating, planer technology. Reliability and availability factors of less than 100% are attributed to subcomponents, which have since been redesigned to correct the issues. The key events can be summarized as follows:

June 28 thru July 3, 2003: Overly sensitive hydrogen sensors inside the outdoor
enclosure caused several shutdowns during test runs. This was compounded by
calibration drift that increased their sensitivity levels further. During the 4 AM run on
June 28 the hydrogen sensors forced a complete system shutdown. This event was
categorized as an Unscheduled Outage and an unsuccessful start, impacting both
availability and reliability totals. Following this run, further operation was curtailed by
shutting down the PLC (remotely from Spokane) until onsite service could be performed

on July 3. This outage period from the afternoon of June 28 until the morning of July 3 was categorized as a Scheduled Outage. During a scheduled outage period, the fuel cell system was considered to be "not capable of providing service", and the availability total was therefore impacted for the months in which the outages occurred. Since there were no attempted system starts during the scheduled outage, the reliability calculation does not include this period.²

To correct the sensor problem, new instruments were installed based on the ReliOn design currently used in the Independence 1000[™] fuel cell. There have been no further problems since July 2003. Hydrogen sensors are now designed into ReliOn fuel cell modules and are no longer used inside commercial shipments of the outdoor enclosure.

- July 11, 12, 22: Outages were scheduled through the 4 PM runs on these days to allow onsite service work. This impacted availability, but not reliability.
- October 27 thru 28, 2003: Hydrogen gas vendor did not properly connect gas cylinders.
 Fuel supply exhausted on October 27. The fuel cell system started for every scheduled
 test run, but lack of hydrogen forced the system to shut down. Again, this impacted
 availability, but not reliability.
- December 28 thru 29, 2003: Hydrogen gas vendor missed delivery scheduled for Christmas Eve. Fuel supply exhausted on December 28. The fuel cell system started for every scheduled test run, but lack of hydrogen forced the system to shutdown. Again, this impacted availability, but not reliability.
- December 29, 2003 thru January 2, 2004: Pad heaters applied to the bottom of the fuel cells shorted and tripped the enclosure power breaker. The computer, PLC, and data logger in the enclosure continued running until the batteries were depleted. The system was designed to start from a PLC clock signal and not on loss of AC power. Therefore, the fuel cells did not start. This impacted both availability and reliability. These pad heaters are no longer used in ReliOn outdoor enclosures. They have been replaced by a much more robust design.

Intermittent cracking of the molded plastic outer covers on the fuel cell module cartridges were detected during the test program. To address this issue, a new design of fuel cell cartridge, incorporating a foam aluminum heat sink and aluminum current collectors was installed in one of the modules in January 2004. The installation of this new cartridge type provided additional field service data for the design. Since the beginning of 2004, this new cartridge design has been included with all new Independence 500™ fuel cells delivered to customers. The main benefits of the new aluminum heat sink cartridge design are expanded temperature range, and improved force application. The cartridges were redesigned with an aluminum cover to provide compression force to the MEA. The new aluminum cover cartridges have performed flawlessly through the end of the test program.

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² Availability and Reliability definitions based on North American Electric Reliability Council, Glossary of Terms, August 1996.

16.0 <u>Decommissioning/Removal/Site Restoration</u>

Upon completion of the successful test program, the FAA requested that the test site be converted to a commercially operating backup power system. This work was completed at the site by ReliOn Application Engineers during the week of June 7, 2004. The conversion effort primarily involved replacement of the six (6) Independence 500^{TM} fuel cells with one (1) current model Independence 1000^{TM} system.

The upgraded system specifications are:

- System Voltage: Nominal 24 VDC
- System Current: 40 Amps
- System Backup Capacity: 48 kWh
- Operating Temperature Range: -40 deg. C to + 46 deg. C

The system was configured to provide the following startup options for a fully functional backup power system for the FAA's RTR site:

- Dry Contact Closure
- Loss of AC power
- Low DC Bus Voltage user configurable to 22, 23, 24, or 25 VDC trip point

The specific modifications which were undertaken at the McChord RTR site are as follows:

- 1. Removal of unnecessary test equipment in Outdoor Enclosure
 - a. PLC control systems
 - b. Independence 500 Communications systems
 - c. Leave extra equipment bays for storage space
- 2. Installation of ReliOn control system in Outdoor Enclosure
 - a. Loss of AC Power start relay
 - b. Low voltage startup
 - c. Startup control box for hydrogen solenoid & ventilation fan
- 3. Modification of Hydrogen delivery system
 - a. Remove fuel cell cabinet regulators
 - b. Configure hydrogen delivery system for use with up to two Independence 1000s
 - c. Configure hydrogen delivery system to utilize both Hydrogen cabinets
 - d. Upgrade the hydrogen hose and manifold
- 4. Installation of cold weather modifications
 - a. Install upgraded heaters
 - b. Remove existing bleed system
 - c. Install new cold weather bleed system modifications
 - d. Install cold weather exhaust modifications
- 5. Retrofit enclosure hardware for use with Independence 1000
 - a. Replace rear door for fuel cell exhaust
 - b. Remove unnecessary rack hardware
 - c. Install additional necessary insulation

- 6. Removal of unnecessary testing hardware
 - a. Removal of DC load bank
 - b. Removal of enclosure batteries
 - c. Rewiring to provide output power of enclosure directly to RTR DC bus
 - d. Removal of DC load bank contactors and enclosure hardware
- 7. Install alarm wiring between fuel cell enclosure and FAA wireless alarm panel in RTR building
- 8. Provide updated drawing package to FAA

17.0 Additional Research/Analysis

The load bank used for Phase 1 testing consists of three resisters nominally rated at 0.7 ohm. The resisters are configured in parallel to provide the load increments at 24 to 27 Volts. The actual power dissipated at each increment depends on the voltage at each run and effective resistance of the load bank at its operating temperature. During each Phase 1 test run, the effective power spiked initially, and then settled down as the resisters heat up. At higher ambient temperatures, the power at the load bank near the end of the 3 kW increment can be almost 300 W below the initial maximum. An example of this initial spike and subsequent drop in power can be seen in Figure 9. This plot shows the 3 kW increment during the 4:00 PM run on June 5, 2003 when the indicated ambient temperature was over 38°C.

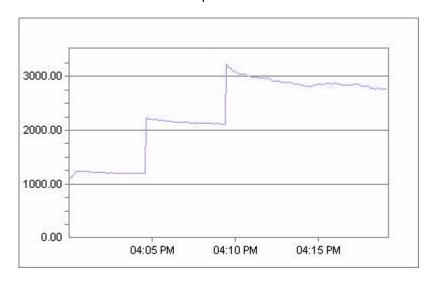


Figure 9. 4:00 PM Run, 6/5/2003

To verify that the drop in power at the load bank was a function of resister behavior and not a decrease in fuel cell performance during the run period, a constant load test using a 4 kW Dynaload was conducted on July 11, 2003. The test results are summarized in Figure 10 and show that the fuel cell system can maintain a constant net load at or above 3000 W.

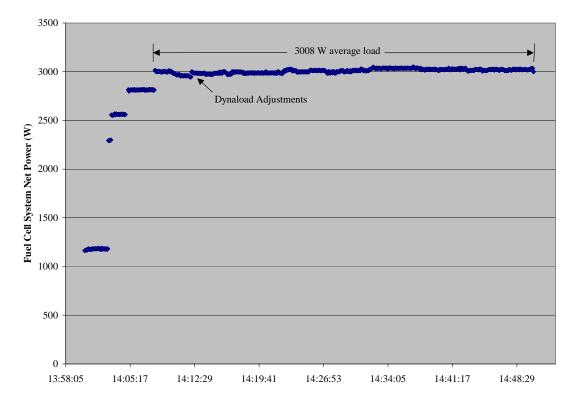


Figure 10. Constant Power Dynaload Test

Based on the results of the constant load test, the connecting lugs on the load bank resisters were adjusted to increase the current flow and average power delivered by the fuel cell system at the 3 kW set point. A trace of fuel cell system output power following these adjustments is shown in Figure 11.

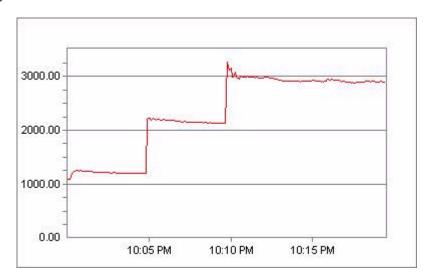


Figure 11. 10:00 PM Run, 8/7/2003

ReliOn PEM Fuel Cell Backup Power Demonstration Final Report

18.0 <u>Conclusions/Summary</u>

Through the end of the test program, the system was monitored for over 8800 hours and accumulated over 1106 successful starts for a total fuel cell run time of 418.9 hours. Total reliability (Actual Starts/Attempted Starts) for the entire test program was 99.4%. Total availability (Actual Run Time In Scheduled Period/Scheduled Run Time in Period) for the entire test program was 97.4%. The fuel cells themselves were very reliable throughout the 1 year demonstration program, presenting an effective presentation of ReliOn's modular, air cooled, self hydrating, planer technology. Total system reliability and availability factors of less than 100% were attributed to sub-components, which have since been replaced or redesigned.

<u>Appendix</u>

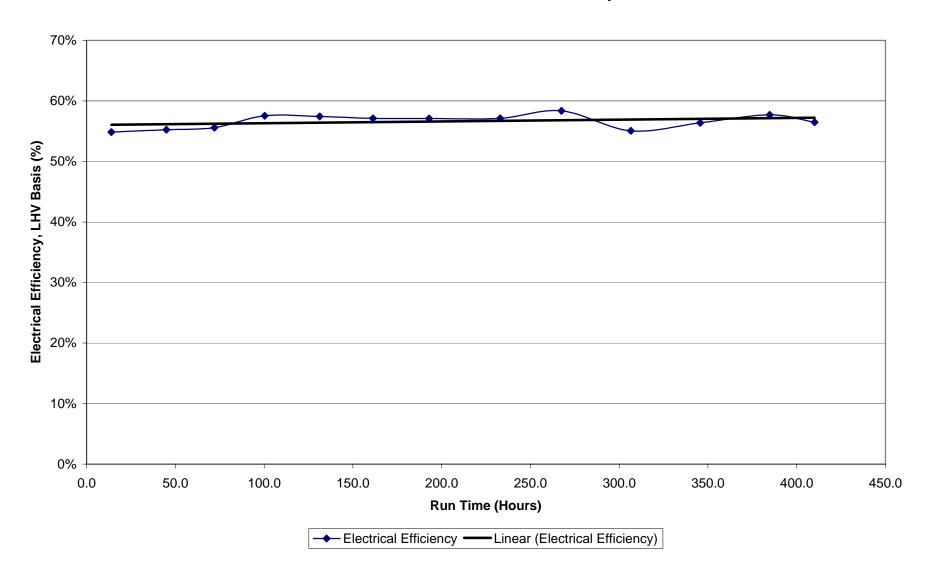
Appendix 1 – Monthly Performance Data Appendix 2 – Maintenance Logs

Appendix 1a -- ReliOn PEM Fuel Cell Project Totals for CERL II, McChord AFB.

Fuel Cell Site Grand Totals

Run Time (Hours)	358.8
Time in Period (Hours)	8808.3
Attempted Starts	1113
Actual Starts	1106
Reliability (%)	99.37%
Availability (%)	97.42%
Energy Produced (kWe-hrs AC)	834.2
Output Setting (kW)	3.00
Average Output (kW)	2.32
Capacity Factor (%)	3.16%
Fuel Usage, LHV (BTUs)	5.02E+06
Fuel Usage (SCF)	18844.1
Electrical Efficiency, LHV (%)	56.69%
Thermal Heat Recovery (BTUs)	0
Heat Recovery Rate (BTUs/hour)	0.00
Thermal Efficiency, LHV (%)	0.00%
Overall Efficiency, LHV (%)	56.69%
Number of Scheduled Outages	5
Scheduled Outage Hours	5.3
Number of Unscheduled Outages	6
Unscheduled Outage Hours	6.06

Appendix 1b ReliOn McChord Electrical Efficiency



PEM Fuel Cell Performance Data

System Number: System Number: I Commission Date: 17-Apr-03 Site Location(City,State): Tacoma, WA

Site Name: FAA RTR Site, McChord AFB Fuel Cell Type: Modular PEM

Fuel Type: Hydrogen Maintenance Contractor: Relion

Lower Heating Value: 366.6 (Btu/scf) Studies (Btu/scf) Site Location(City,State): Tacoma, WA

Site Location(City,S

Month	Total Time in Month (Hours)	Total Run Time During Month (Hours)	Run Time Du	uring Load Ban (Hours)	k Test Periods	Run Time D	uring RTR Load (Hours)	d Test Periods	Total Run Time During Scheduled Test Periods	Attempted Starts	Actual Starts	Availability (%)	Reliability (%)	Energy Produced (kWe-hrs AC)	Plant Capacity (kW)	Average Output (kW)	Capacity Factor (%)	Fuel Usage, LHV (BTUs)	Fuel Usage (SCF)	Electrical Efficiency LHV Basis (%)	Thermal Heat Recovery (BTUs)	Heat Recovery Rate (BTUs/hour)	Thermal Efficiency LHV Basis (%)	Overall Efficiency LHV Basis (%)	Number of Scheduled Outages	Scheduled Outage Hours	Number of Unscheduled Outages	Unscheduled Outage Hours
			Scheduled	Actual	Cumulative	Scheduled	Actual	Cumulative	Cumulative			*1	*2	insert produced energy	insert plant capacity	*3	*4	insert fuel consumption	insert fuel consumption	*5	insert heat recovery	*6	*7	*8	insert value	insert value	insert value	insert value
April	312	14.0	14	14.0	14	0	0.0	0.0	14.0	42	42	100%	100%	33.373	3	2.38	3.57%	207748.6	779.25	54.84%	0	0	0.00%	54.84%	0	0	0	0
May 20	744	31.0	31	31.0	45	0	0.0	0.0	45.0	93	93	100%	100%	73.432	3	2.37	3.29%	453748.4	1701.98	55.25%	0	0	0.00%	55.25%	0	0	0	0
June ²¹	720	27.8	30	27.0	72	0	0.0	0.0	72.0	82	82	90.0%	100%	62.411	3	2.31	2.89%	383236.6	1437.50	55.60%	0	0	0.00%	55.60%	1	2.6	1	0.3
July ²²	744	33.6	31	28.3	100.3	0	0.0	0.0	100.3	83	83	91.4%	100%	59.684	3	2.11	2.67%	354048.1	1328.01	57.55%	0	0	0.00%	57.55%	4	2.7	0	0
August	744	31.8	31	31.0	131.3	0	0.0	0.0	131.3	93	93	100%	100%	72.015	3	2.32	3.23%	428031.0	1605.52	57.44%	0	0	0.00%	57.44%	0	0	0	0
September	720	30.0	30	30.0	161.3	0	0.0	0.0	161.3	90	90	100%	100%	66.836	3	2.23	3.09%	399506.7	1498.52	57.12%	0	0	0.00%	57.12%	0	0	0	0
October 23	744	31.7	31	29.7	191.0	2	2.0	2.0	193.0	94	94	95.7%	100%	68.078	3	2.29	3.05%	407102.0	1527.01	57.09%	0	0	0.00%	57.09%	0	0	4	1.3
November	720	40.0	30	30.0	221.0	10	10.0	12.0	233.0	95	95	100%	100%	75.213	3	2.51	3.48%	449488.2	1686.00	57.13%	0	0	0.00%	57.13%	0	0	0	0
December 24	744	34.5	31	28.5	249.5	8	6.1	18.0	267.5	97	90	91.9%	93%	67.522	3	2.37	3.03%	394986.8	1481.57	58.36%	0	0	0.00%	58.36%	0	0	1	4.5
January 25	744	39.0	31	31.0	280.5	8	8.0	26.1	306.6	97	97	100%	100%	63.103	3	2.04	2.83%	391288.9	1467.70	55.06%	0	0	0.00%	55.06%	0	0	0	0
February	696	39.1	29	29.0	309.5	10	10.1	36.2	345.7	92	92	100%	100%	70.793	3	2.44	3.39%	428580.7	1607.58	56.39%	0	0	0.00%	56.39%	0	0	0	0
March 26	744	39.4	31	31.0	340.5	8	8.1	44.2	384.7	97	97	100%	100%	75.088	3	2.42	3.36%	444171.9	1666.06	57.71%	0	0	0.00%	57.71%	0	0	0	0
April 27	432.3	27.0	18.3	18.3	358.8	6	7.0	51.3	410.1	58	58	100%	100%	46.636	3	2.54	3.60%	281889.8	1057.35	56.48%	0	0	0.00%	56.48%	0	0	0	0

Run To	ning Time tals	e in Period Hours)	Total Run Time During Month	Total Scheduled Run Time	Total Actual Run Time	Load Bank Test Cummulative Run Time	Total Scheduled Run Time	Total Actual Run Time	RTR Load Test Cummulative Run Time	Total Run Time During Scheduled Test Periods	Total Attempted Starts	Total Actual Starts	Total Availability (*9)	Total Reliability	Total Energy Produced	Average Output Setting	Total Average Output (*10)	Total Capacity Factor (*11)	Total Fuel Usage	Total Fuel Usage	Average Electrical Efficiency (*12)	Total Thermal Heat Recovery (*13)	Average Thermal Efficiency (*14)	Average Overall Efficiency (*15)	Total Outages Tot	al Hours Total Outages	Total Hours
	88	3808.3	418.9	368.3	358.8	358.8	52	51.3	51.3	410.1	1113	1106	97.4%	99.4%	834.187	3	2.32	3.16%	5.02E+06	18844.07	56.69%	0 0	0.00%	56.69%	5	5.3 6	6.1

Appendix 1.xls\Fuel Cell #1

Appendix 1c -- PEM Fuel Cell Performance Data. McChord AFB.

- Availability Run Time / Time in Period Reliability Actual Starts / Attempted Starts Average Output Energy Produced / Run Time Average Output / Output Setting (Total Energy Produced * 3414 BTUs/kW-hr) / Total Fuel Usage Capacity Factor Electrical Efficiency
- Thermal Heat Recovery / Run Time Heat Recovery Rate
- Thermal Heat Recovery / Total Fuel Usage Electrical Efficiency + Thermal Efficiency Thermal Efficiency Overall Efficiency Sum Total Run Time / Sum Total Hours in Period *9 Total Availability
- Total Energy Produced / Total Run Time *10 Total Average Output Total Energy Produced / (Total Capacity * Total Time in Period) Total Capacity Factor
- Avg. Electrical Efficiency (Total energy produced * 3414 BTUs/kWh) / Total Fuel Usage Avg. Heat Recovery Rate Total Thermal Heat Recovery / Total Run Time *13 Avg. Thermal Efficiency Total Thermal Heat Recovery / Total Fuel Usage Avg. Electrical Efficiency + Avg. Thermal Efficiency Avg. Overall Efficiency
- Puget Sound Energy Residential General Service, effective April 10, 2003

Delivery Charge = 26.113 ¢ per therm; Low Income Program = 0.405 ¢ per therm; Cost of Gas = 44.419 ¢ per therm; Conservation Charge = 0.184 ¢ per therm Total Charge = 71.121 ¢ per therm

For more information see http://www.pse.com/account/rates/ratesgas.html

Puget Sound Energy Commercial and Industrial General Service, effective April 10, 2003

Delivery Charge = 23.742 ¢ per therm; Low Income Program = 0.335 ¢ per therm; Cost of Gas = 43.499 ¢ per therm; Conservation Charge = 0.184 ¢ per therm Total Charge = 67.760 ¢ per therm

For more information see http://www.pse.com/account/rates/ratesgas.html

Tacoma Power Residential Service, Schedule A-1, effective March 31, 2003 for Tacoma and Pierce County Energy Charge = \$.030349 per kWh; Delivery Charge = \$.027219 per kWh

Customer Charge = \$5.50 per month for all but collectively metered apartments; \$4.50 per month for collectively metered apartments

For more information see http://www.ci.tacoma.wa.us/power/Rates/residential.htm

Tacoma Power Commercial Service, Schedule G General Service, effective March 31, 2003 for Tacoma and Pierce County Energy Charge = \$.032063 per kWh; Delivery Charge = \$5.36 per kW based on billing demand for period Customer Charge = \$46.00 per month

For more information see http://www.ci.tacoma.wa.us/power/Rates/commercial.htm

- Includes three (3) runs on May 28 and May 29 when data uploader was offline.
- Does not include outage on June 28, 29, 30
- *22 Does not include outages on July 1-3, July 11-12, and July 22. Includes three (3) runs for July 8 & July 9 when data uploader was offline.
- *23 Three of Six fuel supply cylinders not properly connected. System operated on three cylinders only until exhausted during 10 PM run October 26. Special fuel delivery occurred on October 28. Fuel cells continued to start, but produced no power for three runs on October 27 and one run on October 28.
- Gas supply vendor missed regular delivery scheduled for December 24. Fuel supply exhausted during 4 AM run on December 28. Fuel cells started but shut *24 down within 1 minute for 9 AM, 4 PM, and 10 PM runs on December 28, and 4 AM run on December 29. Fuel supplied replenished prior to 4 PM run on December
 - Outdoor enclosure heater developed electric short during 10 PM run on December 29, tripping enclosure power breaker and leading to safety shutdown. Electric short also damaged data logging computer. Fuel cell system restarted for 4 PM and 10 PM runs on December 31. No data recorded until Temporary computer was installed on January 2. Energy Produced and Fuel Usage not recorded when data uploader was offline on Dec 31.
- Includes fuel cell system starts and run time when data uploader was offline. Energy Produced and Fuel Usage not recorded when data uploader was offline on *25
- *26 Includes fuel cell system starts and run time when data uploader was offline during 4 PM run on March 8.
- Phase 1 and Phase 2 test programs shut down following 4 AM run on April 19, 2004

Page 2 of 2 Appendix 1.xls\Fuel Cell #1

Appendix 1d -- ReliOn PEM Fuel Cell Project Data Summary for CERL II, McChord AFB.

					Site Perfe	ormance	Matrix				
System No.	Total Run Hours	Scheduled Hours	Total Hours in Period	Attempted Starts	Actual Starts	Reliability (%)	Availability (%)	Capacity Factor (%)	Total Energy Produced (kWe-hrs AC)	Average Output (kW)	Electrical Efficiency LHV Basis (%)
	359	368	8808	1113	1106	99.4%	97.4%	3.2%	834	2.32	56.7%

Installation Date: 1/14/03

Maintenance Performed:

runs most likely OK.	<u>Date</u>	Operator	<u>Task</u>
5/23/2003 Snow Subrack 6 data not uploading from 10 PM run. Exit and re-launch CERL II Terminal Server. 5/26/2003 Snow Subrack 6 data not uploading since 4 PM run on 5/26/03 (Memorial Day weekend). Exit and re-launch CERL II Terminal Server. 5/27/2003 Snow Subrack 6 data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/27/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	2/12/2003	Hager	Cartridge Serial # 3309 indicated failure, Unit 6, Cartridge slot #3. Brought back to Avista Labs for investigation
5/26/2003 Snow Subrack 6 data not uploading since 4 PM run on 5/26/03 (Memorial Day weekend). Exit and re-launch CERL II Terminal Server. 5/27/2003 Snow Subrack 6 data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/27/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM. Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	4/17/2003		Start Phase 1 Test Program
Server. 5/27/2003 Snow Subrack 6 data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/27/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	5/23/2003	Snow	Subrack 6 data not uploading from 10 PM run. Exit and re-launch CERL II Terminal Server.
5/27/2003 Snow Subrack 6 data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/27/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	5/26/2003	Snow	Subrack 6 data not uploading since 4 PM run on 5/26/03 (Memorial Day weekend). Exit and re-launch CERL II Terminal
5/27/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.			Server.
5/28/2003 Snow All subracks data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	5/27/2003	Snow	Subrack 6 data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server.
5/28/2003 Snow All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server. 5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	5/27/2003	Snow	All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server.
5/28/2003 Snow Exit and re-launch CERL II Terminal Server at 17.40. 5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	5/28/2003	Snow	All subracks data not uploading from 4 AM run. Exit and re-launch CERL II Terminal Server.
5/29/2003 Snow Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost runs most likely OK.	5/28/2003	Snow	All subracks data not uploading from 4 PM run. Exit and re-launch CERL II Terminal Server.
runs most likely OK.	5/28/2003	Snow	Exit and re-launch CERL II Terminal Server at 17.40.
	5/29/2003	Snow	Discovered CERL II TS not connected at 9.45 AM Exit and re-set TS. 5-28-03 22:00 and 5-29-03 04:00 data will be lost but
			runs most likely OK.
6/6/2003 Snow Replace all Gore cartridges in SR 4 and SR 6 with 3M/Centipede cartridges. Install Version 1.5M chip.	6/6/2003	Snow	Replace all Gore cartridges in SR 4 and SR 6 with 3M/Centipede cartridges. Install Version 1.5M chip.
6/17/2003 Snow Cartridge bus fuse blew on SR 4 on 6-15-2003. Replace with 35 Amp fuse.	6/17/2003	Snow	
	6/26/2003	Snow	16.00 run: Approx. 4 min. into 2000 W segment, load fell back to ~1200 W. Load increased to ~2000 W briefly then fell back
to ~1200 W. Appears to be related to load bank, not fuel cells.			to ~1200 W. Appears to be related to load bank, not fuel cells.
6/27/2003 Snow Intermittant load bank behavior continuing. Switching between 1, 2, and 3 kW during run.	6/27/2003	Snow	
6/28/2003 Snow 4.00 run: Load completely off-line. Shut down test due to safety concerns associated with failed load bank.	6/28/2003	Snow	
7/3/2003 Snow Load bank and relays OK. Found low-level hydrogen signals with Tif detector. Suspect hydrogen leaks from solenoid valve	7/3/2003	Snow	Load bank and relays OK. Found low-level hydrogen signals with Tif detector. Suspect hydrogen leaks from solenoid valves
or manifold on SR1. Replaced SR1 with spare unit. Replace several cartridges. Conduct extra full run at 14:00. Special			or manifold on SR1. Replaced SR1 with spare unit. Replace several cartridges. Conduct extra full run at 14:00. Special test
run using auto-start during 4:00 PM run period. Manually control load bank at 1 kW and 2 kW. Set PLC to ramp to 2 kW c			run using auto-start during 4:00 PM run period. Manually control load bank at 1 kW and 2 kW. Set PLC to ramp to 2 kW only
for the weekend. Return on 7-6 to service system.			for the weekend. Return on 7-6 to service system.
7/6/2003 Snow System maintenance activities continued through 4:00 PM run. Load bank held at 1 kW during entire run.	7/6/2003	Snow	System maintenance activities continued through 4:00 PM run. Load bank held at 1 kW during entire run.
7/8/2003 Data uploader offline for 4:00 PM & 10:00 PM runs	7/8/2003		Data uploader offline for 4:00 PM & 10:00 PM runs
7/9/2003 Data uploader offline for 4:00 AM run	7/9/2003		Data uploader offline for 4:00 AM run
7/11/2003 Snow Found leaking Gore cartridge in SR5. Hydrogen leaks causing H2 sensor trips. Replace all Gore cartridges in SR5. Insta	7/11/2003	Snow	Found leaking Gore cartridge in SR5. Hydrogen leaks causing H2 sensor trips. Replace all Gore cartridges in SR5. Install
version 1.6r chip in SR5. Install air flow baffles in SR5. Removed spare unit and replaced original into SR1 space. SR1,			version 1.6r chip in SR5. Install air flow baffles in SR5. Removed spare unit and replaced original into SR1 space. SR1,
SR4, SR5, and SR6 now equipped with 3M/Centipede cartridges. SR1, SR4, and SR5 have air flow baffles. SR1 and SR			SR4, SR5, and SR6 now equipped with 3M/Centipede cartridges. SR1, SR4, and SR5 have air flow baffles. SR1 and SR5
have version 1.6r chip. SR4 and SR6 have version 1.5m chip. Perform extra manual test runs. Perform Dynaload test on			have version 1.6r chip. SR4 and SR6 have version 1.5m chip. Perform extra manual test runs. Perform Dynaload test on
system. System maintains >3000 W for over 30 minutes. Determined that static resister load bank requires adjustment.			system. System maintains >3000 W for over 30 minutes. Determined that static resister load bank requires adjustment.
7/22/2003 Snow Replace blown fuses on SR4 and SR6. Adjust tap location on R3 of load bank to reduce resistance and increase current a	7/22/2003	Snow	Replace blown fuses on SR4 and SR6. Adjust tap location on R3 of load bank to reduce resistance and increase current at 3
kW setpoint. Placed clipboards with cylinder manifold pressure log in cylinder cabinets.			kW setpoint. Placed clipboards with cylinder manifold pressure log in cylinder cabinets.
H2 sensor maintenance activities continued through 4:00 PM run. No 4:00 PM run data.			
8/7/2003 Snow Replace all fuses with 50 Amp Fast Blow. Install version 1.7r chip in SR1, SR4, SR5, SR6. Replace SMC sensors in	8/7/2003		
enclosure bays 1 & 2 with sensors calibrated to 2000 ppm. Set north hydrogen supply pressure to 48 psig. Set south			
hydrogen supply pressure to 56 psig. Replace 1 cartridge in SR5, 1 cartridge in SR6, 3 cartridges in SR 2.		l i	tericiosure bays i & 2 with sensors calibrated to 2000 ppm. Set north hydrogen supply pressure to 40 psig. Set south

Installation Date: 1/14/03

Maintenance Performed:

Date	Operator	<u>Task</u>
9/4/2003	Snow	Reset PLC clock to laptop clock to eliminate end-of-run alarms.
9/10/2003	Snow	Install 3M/Centipede cartridges in SR2 and SR3. Install version 1.7r chip in SR2 and SR3. Install air flow baffles in SR2 and SR3.
9/13/2003	Snow	Found leaking CPC fitting on bleed line in cabinet 1. Found unseated CPC fitting on bleed line in cabinet 2. Re-install SR3. Replaced 3 cracked cartridges. Replace 3 SMC sensors with Avista hydrogen sensors with 7500 ppm trip point.
10/26/2003		System low power. Appears to be loss of fuel. Asking AirGas supplier to check status of ball valves. AirGas reported gas cylinders empty.
12/28/2003		Out of fuel near end of 4 AM run. RTR run at 9 AM started but shut down. Also, load bank tests at 4 PM and 10 PM started but shut down.
12/29/2003		Out of fuel. Load bank test at 4 AM started but shut down. Airgas delivered 6 full cylinders following 4 AM run. 4 PM run OK.
12/29/2003		Heaters shorted prior to 10 PM run & tripped 20 Amp breaker in enclosure AC power distribution panel. Rectifier offline due to breaker trip. Battery voltage was at 21 V at beginning of run and insufficient to start all fuel cells. PLC continued to run load bank until batteries depleted.
12/30/2003		Depleted batteries did not provide sufficient power to run PLC and start 4 AM, 4 PM, or 10 PM fuel cell runs.
12/31/2003	Snow	Found heater shorted & 20 Amp breaker tripped in enclosure AC power distribution panel. Found 10 Amp fuse (F9) to rectifier blown, although not sure if fuse F9 tripped during diagnostic evaluation. One of two reaction air fans not operating on SR1. SR1 giving low power. Replace SR1.
1/2/2004	Snow	Install Foam cartridges in SR3. Install version 1.9r (24 V, no H2) firmware
2/10/2004		Subracks 1 and 2 shut down during 10 PM, and 4 AM runs during cold temperatures. Faulty fuse holder for subrack heaters in cabinet 1 popped open disconnecting power to fuel cell heaters.
2/11/2004	Hager	Reconnected heater fuse in cabinet 1. Tested all heaters to ensure operation. Replaced 1 faulty cartridge and three cracked cartridges. Verified all cartridge serial numbers. Inpected hydrogen enclosure and piping for leaks. Ran system test.
3/10/2004		SR5 not operating from 4 AM run.
3/15/2004	Snow	Found corroded fuse and fuse holder in SR5. Fuse tested OK. Cleaned fuse holders in all units. Installed new fuse in SR5. Ran two 20 minute tests.

Appendix 2b -- Cartridge Log for CERL II, McChord AFB.

| Subrack 1 | "Original" | April 17, 2003
S/N Membrane

 | | e 6, 2003 |
 | 3, 2003 | July | | igust 7, 2003 | | September 13, 2003
 | October 15, 2003 | December 9, 2003 | | er 31, 2003 |
 | 2, 2004 | January 8, 2004 | February 12, 2004 S/N Membrane | March 9, 2004 | March 15, 20
 | |
|---|--
--
--
---	--	--	---	---
--	--	--	---	
--	--	--	--	
--	--	--		
Slot	S/N Membrane			

 | | Membrane | | | |
 | Membrane S | /N | Membrane S/N | | ne S/N Membrane |
 | S/N Membrane | | | Membrane |
 | Membrane | | | |
 | mbrane |
| Slot 1 | 3393 Gore | 3882 3M

 | | 2 3M/Centi |
 | 2 3M/Centi ^d | | | 018 3M/Cent | | 4018 3M/Centi
 | 4018 3M/Centi | 4018 3M/Centi | | 3M/Centi |
 | 3M/Centi | 4018 3M/Centi | 4018 3M/Centi | 4018 3M/Centi | 4018 3M/C
 | |
| Slot 2 | 3335 Gore | 3808 3M

 | | 8 3M/Centi | _
 | 4 3M/Centi | | | 964 3M/Cent | | 3964 3M/Centi
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 | 3M/Centi | 3964 3M/Centi | 3964 3M/Centi | 3964 3M/Centi | 3964 3M/C
 | |
| Slot 3 | 3321 | 3809 3M

 | | 9 3M/Centi ^a |
 | 1 3M/Centi | | | 017 3M/Cent | | 4017 3M/Centi
 | 4017 3M/Centi | 4017 3M/Centi | | 3M/Centi |
 | 3M/Centi | 4017 3M/Centi | 3711 3M/Centi | 3711 3M/Centi | 3711 3M/C
 | |
| Slot 4 | 3585 3M | 3744 3M

 | | 4 3M/Centi |
 | 3 3M/Centi | | | 013 3M/Cent | | 4013 3M/Centi
 | 4013 3M/Centi | 4013 3M/Centi | | 3M/Centi |
 | 3M/Centi | 4013 3M/Centi | 4013 3M/Centi | 4013 3M/Centi | 4013 3M/C
 | |
| Slot 5 | 3597 3M | 3750 3M

 | | 0 3M/Centi |
 | 3M/Centi | | | 016 3M/Cent | | 3944 3M/Centi
 | 3944 3M/Centi | 3944 3M/Centi | | 3M/Centi |
 | 3M/Centi | 3944 3M/Centi | 3944 3M/Centi | 3944 3M/Centi | 3944 3M/C
 | |
| Slot 6 | 3285 Gore | 3585 3M

 | | 5 3M/Centi |
 | 4 3M/Centi | | | 054 3M/Cent | | 4016 3M/Centi
 | 4081 3M/Centi | 3841 3M/Centi ^d | | 3M/Centi |
 | 3M/Centi | 3879 3M/Centi | 4017 3M/Centi | 4017 3M/Centi
3879 3M/Centi | 4017 3M/C
 | |
| Slot 7 | 3378 Gore
3381 Gore | 3742 3M

 | | 2 3M/Centi
2 3M/Centi |
 | 3M/Centi
3M/Centi | | | 841 3M/Cent
023 3M/Cent | | 3841 3M/Centi
4023 3M/Centi
 | 3841 3M/Centi
4023 3M/Centi | 4081 3M/Centi
4023 3M/Centi | | 3M/Centi
3M/Centi |
 | 3M/Centi
3M/Centi | 4081 3M/Centi
4023 3M/Centi | 3879 3M/Centi | 3706 3M/Centi | 3879 3M/C
3706 3M/C
 | /Centi |
| Slot 8 | | 3782 3M

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 | | | 3706 3M/Centi | |
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| Slot 9 | 3397 Gore | 3743 3M

 | | 3 3M/Centi d |
 | 3M/Centi | | | 009 3M/Cent | | 4009 3M/Centi
 | 4009 3M/Centi | 4009 3M/Centi | | 3M/Centi |
 | 3M/Centi | 4009 3M/Centi | 4009 3M/Centi | 4009 3M/Centi |
 | /Centi |
| Slot 10 | 3301 Gore | 3785 3M

 | 3/8 | 5 3M/Centi | 360
 | 7 3M/Centi | 3607 | 3M/Centi 3 | 607 3M/Cent | i 3607 3M/Centi ^d | 4020 3M/Centi
 | 4020 3M/Centi | 4020 3M/Centi | 4020 | 3M/Centi | 4020
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| Subrack 2 | "Original" | April 17, 2003

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| 01-1-0 | 3279 Gore | 3279 Gore

 | | 9 Gore |
 | Gore | | | 279 Gore | 3727 3M/Centi | 3727 3M/Centi
 | 3727 3M/Centi | 3727 3M/Centi | | 3M/Centi |
 | 3M/Centi | 3727 3M/Centi | 3668 3M/Centi | 3668 3M/Centi | 3668 3M/C
 | |
| Slot 2 | 3297 Gore | 3297 Gore

 | | 7 Gore |
 | Gore | | | 327 Gore | 4051 3M/Centi | 4051 3M/Centi
 | 4051 3M/Centi | 4051 3M/Centi | | 3M/Centi |
 | 3M/Centi | 4051 3M/Centi | 3692 3M/Centi | 3692 3M/Centi |
 | /Centi |
| Slot 3 | 3362 Gore
3432 Gore | 3362 Gore

 | | 2 Gore |
 | Gore | | | 362 Gore | 4069 3M/Centi ^a
4071 3M/Centi | 4056 3M/Centi
4071 3M/Centi
 | 4056 3M/Centi | 4056 3M/Centi ^d
4071 3M/Centi | | 3M/Centi |
 | 3M/Centi | 3562 3M/Centi
4071 3M/Centi | 3400 3M/Centi
4071 3M/Centi | 3400 3M/Centi | 3400 3M/C
3607 3M/C
 | |
| Slot 4 | | 3432 Gore

 | | 2 Gore | | | |
 | Gore | | | 432 Gore | |
 | 4071 3M/Centi | | | 3M/Centi |
 | 3M/Centi | | | 3607 3M/Centi |
 | /Centi |
| Slot 5 | 3357 Gore | 3357 Gore

 | | 7 Gore |
 | 7 Gore | | | 276 Gore | 4074 3M/Centi | 4074 3M/Centi
 | 4074 3M/Centi | 4074 3M/Centi | | 3M/Centi |
 | 3M/Centi b | 3868 3M/Centi | 3868 3M/Centi | 3868 3M/Centi |
 | /Centi |
| Slot 6 | 3573 | 3300 Gore

 | | 0 Gore |
 | Gore | | | 300 Gore | 4075 3M/Centi | 4075 3M/Centi
4077 3M/Centi
 | 4075 3M/Centi | 4075 3M/Centi | | 3M/Centi |
 | 3M/Centi | 4075 3M/Centi | 3682 3M/Centi | 3682 3M/Centi |
 | /Centi |
| Slot 7
Slot 8 | 3287 Gore | 3335 Gore
3287 Gore

 | | 5 Gore |
 | Gore
Gore | | | 335 Gore
287 Gore | 4077 3M/Centi
4081 3M/Centi | 3743 3M/Centi
 | 3750 3M/Centi | 3750 3M/Centi
3743 3M/Centi | | 3M/Centi
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 | 3M/Centi
3M/Centi | 3750 3M/Centi
3743 3M/Centi | 3693 3M/Centi | 3693 3M/Centi
3743 3M/Centi | 3693 3M/C
 | /Centi |
| Slot 8
Slot 9 | 3287 Gore
3256 Gore | 3256 Gore

 | | 7 Gore
6 Gore |
 | Gore Gore | | | 256 Gore | 4081 3M/Centi | 4083 3M/Centi
 | 3743 3M/Centi
4083 3M/Centi | 4083 3M/Centi | | 3M/Centi |
 | 3M/Centi | 4083 3M/Centi | 3743 3M/Centi
4083 3M/Centi | 4083 3M/Centi | 4083 3M/C
 | |
| Slot 10 | 3383 Gore | 3383 Gore

 | | 3 Gore |
 | Gore Gore | | | 385 Gore | 4085 3M/Centi | 4085 3M/Centi
 | 4085 3M/Centi | 4085 3M/Centi | | 3M/Centi |
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| SIUL IU | 3303 GUIE | 3303 3018

 | 338 | JIGUIE | 338
 | Joue | 3363 | 3 | JUJUGUIE | 4000 SIVI/CENTI | 4000 SIVI/CETITI
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| Subrack 3 | "Original" | April 17, 2003

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| Slot 1 | 3379 Gore | 3379 Gore

 | | 9 Gore |
 | Gore | | | 319 Gore | 4073 3M/Centi | 4086 3M/Centi
 | 4086 3M/Centi | 4086 3M/Centi | | 3M/Centi |
 | 3M/Foam | 4166 3M/Foam | 4166 3M/Foam | 4166 3M/Foam | 4166 3M/F
 | |
| Slot 2 | 3324 | 3324 Gore

 | | 4 Gore |
 | 4 Gore | | | 324 Gore | 4073 3M/Centi | 4076 3M/Centi
 | 4076 3M/Centi | 4076 3M/Centi | | 3M/Centi |
 | 3M/Foam | 4130 3M/Foam | 4130 3M/Foam | 4130 3M/Foam | 4130 3M/F
 | |
| Slot 3 | 3342 | 3342 Gore

 | | 2 Gore |
 | 2 Gore | | | 342 Gore | 4086 3M/Centi | 3878 3M/Centi
 | 3878 3M/Centi | 4047 3M/Centi | 4047 | 3M/Centi |
 | 3M/Foam | 4126 3M/Foam | 4126 3M/Foam | 4126 3M/Foam | 4126 3M/F
 | |
| Slot 4 | 3217 | 3217 Gore

 | | 7 Gore |
 | 7 Gore b | | | 395 Gore | 4020 3M/Centi | 4084 3M/Centi
 | 4084 3M/Centi | 4084 3M/Centi | | 3M/Centi |
 | 3M/Foam | 4114 3M/Foam | 4114 3M/Foam | 4114 3M/Foam | 4114 3M/F
 | |
| Slot 5 | 3395 | 3395 Gore

 | | 5 Gore |
 | Gore | | | 301 Gore | 3573 3M/Centi | 3820 3M/Centi
 | 3820 3M/Centi | 3820 3M/Centi | | 3M/Centi |
 | 3M/Foam | 4122 3M/Foam | 4122 3M/Foam | 4122 3M/Foam |
 | /Foam |
| Slot 6 | 3394 | 3394 Gore

 | | 4 Gore |
 | 1 Gore | | | 394 Gore | 3944 3M/Centi | 3874 3M/Centi
 | 3874 3M/Centi | 3874 3M/Centi | | 3M/Centi |
 | 3M/Foam | 4118 3M/Foam | 4118 3M/Foam | 4118 3M/Foam |
 | /Foam |
| Slot 7 | 3338 | 3338 Gore

 | | 8 Gore |
 | 3 Gore | 3338 | | 338 Gore | 3820 3M/Centi | 3584 3M/Centi
 | 3731 3M/Centi | 4072 3M/Centi | | 3M/Centi | 4123
 | 3M/Foam | 4123 3M/Foam | 4123 3M/Foam | 4123 3M/Foam | 4123 3M/F
 | |
| Slot 8 | 3286 | 3286 Gore

 | | 6 Gore |
 | Gore | | | 286 Gore | 4076 3M/Centi | 4072 3M/Centi
 | 4072 3M/Centi | 3819 3M/Centi d | | 3M/Centi |
 | 3M/Foam | 4127 3M/Foam | 4127 3M/Foam | 4127 3M/Foam | 4127 3M/F
 | |
| Slot 9 | 3282 | 3282 Gore

 | 328 | 2 Gore | 328
 | 2 Gore | 3282 | | 282 Gore | 3584 3M/Centi | 4073 3M/Centi
 | 4073 3M/Centi | 4073 3M/Centi | 4073 | 3M/Centi | 4121
 | 3M/Foam | 4121 3M/Foam | 4121 3M/Foam | 4121 3M/Foam | 4121 3M/F
 | /Foam |
| Slot 10 | 3396 | 3396 Gore

 | 339 | 6 Gore | 339
 | 6 Gore | 3396 | Gore 3 | 396 Gore | 4084 3M/Centi | 4000 3M/Centi
 | 4000 3M/Centi | 4000 3M/Centi | 4000 | 3M/Centi | 4169
 | 3M/Foam | 4169 3M/Foam | 4169 3M/Foam | 4169 3M/Foam | 4169 3M/F
 | /Foam |
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| Subrack 4 | "Original" | April 17, 2003

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| Slot 1 | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3320 Gore | S/N Membrane 3318 Gore

 | S/N
371
387 | Membrane
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3877 | Membrane 3
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3905 3M/C
3935 3M/C
 | /Centi
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| Slot 1
Slot 2
Slot 3
Slot 4 | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3361 Gore | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3361 Gore

 | 371
387
372
384 | Membrane 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 2 3M/Centi | 371
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 | mbrane /Centi /Centi /Centi /Centi /Centi /Centi |
| Slot 1
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Slot 6 | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3361 Gore 3382 Gore 3305 Gore | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3361 Gore 3362 Gore 3305 Gore

 | 371
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382 | Membrane 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 0 3M/Centi 5 3M/Centi | 371
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 | Membrane S 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 3 3M/Centi 3 3M/Centi 5 3M/Centi | 3717
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384 | Membrane 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 2 3M/Centi 0 3M/Centi 5 3M/Centi 5 3M/Centi | 371
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 | Membrane S 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 3 3M/Centi 5 3M/Centi 4 3M/Centi | 3717
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mbrane //Centi //Centi //Centi //Centi //Centi //Centi //Centi //Centi |
| Slot 1 Slot 2 Slot 3 Slot 4 Slot 5 Slot 6 Slot 7 Slot 8 | S/N Membrane 3318 Gore 3345 Gore 3340 Gore 3361 Gore 3361 Gore 3362 Gore 3363 Gore 3283 Gore 3283 Gore | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3320 Gore 3382 Gore 3382 Gore 3305 Gore 3283 Gore 3386 Gore 3386 Gore

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 | Membrane S 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 3 3M/Centi 5 3M/Centi 4 3M/Centi 3 3M/Centi | 3717
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 | S/N Membrane : 3857 3M/Centi 3905 3M/Centi 3935 3M/Centi 3955 3M/Centi 4076 3M/Centi 4076 3M/Centi 3861 3M/Centi 3861 3M/Centi 4023 3M/Centi | S/N Membrane 3 3857 3M/Centi 3905 3M/Centi 3905 3M/Centi 3935 3M/Centi 3844 3M/Centi 3955 3M/Centi 3877 3M/Centi 3861 3M/Centi 4023 3M/Centi | 3857 3M/C
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| Slot 1 Slot 2 Slot 3 Slot 4 Slot 5 Slot 6 Slot 7 Slot 8 Slot 9 | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3361 Gore 3382 Gore 3385 Gore 3283 Gore 3283 Gore 3283 Gore 3261 Gore | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3361 Gore 3382 Gore 3305 Gore 3283 Gore 3283 Gore 3261 Gore

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385 | Membrane 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 0 3M/Centi 5 3M/Centi 5 3M/Centi 5 3M/Centi 4 3M/Centi 1 3M/Centi | 371
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 | Membrane S 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 2 3M/Centi 5 3M/Centi 5 3M/Centi 4 3M/Centi 3 3M/Centi 1 3M/Centi | 3717
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3861 | Membrane S/N | Membra 3M/Cent 3M/Ce | ne S/N Membrane i 3717 3M/Centi i 3877 3M/Centi i 3872 3M/Centi i 3842 3M/Centi i 3841 3M/Centi i 3853 3M/Centi i 3744 3M/Centi i 3858 3M/Centi i 3858 3M/Centi i 3858 3M/Centi | S/N Membrane 3717 3M/Centi 3877 3M/Centi 3872 3M/Centi 3722 3M/Centi 3842 3M/Centi 3810 3M/Centi 3825 3M/Centi 3744 3M/Centi 3858 3M/Centi 3851 3M/Centi 3851 3M/Centi | 3717 3M/Centi 3877 3M/Centi 3877 3M/Centi 3722 3M/Centi 3842 3M/Centi 3840 3M/Centi 3840 3M/Centi 3825 3M/Centi 3744 3M/Centi 3858 3M/Centi 3858 3M/Centi 3861 3M/Centi 3861 3M/Centi 3861 3M/Centi
 | S/N Membrane 3722 3M/Centi 5 3877 3M/Centi 3717 3M/Centi 3842 3M/Centi 3810 3M/Centi 3825 3M/Centi 3744 3M/Centi 3858 3M/Centi 3851 3M/Centi 3851 3M/Centi | S/N 3857 3877 3717 3842 3810 3861 3744 3858 3825 | Membrane 3M/Centi | 3857
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3874 | Membrane 3M/Centi | \$\text{S/N} & Membrane \\ 3857 & 3M/Centi \\ 3877 & 3M/Centi \\ 3810 & 3M/Centi \\ 3855 & 3M/Centi \\ 4076 &
3M/Centi \\ 3861 & 3M/Centi \\ 3861 & 3M/Centi \\ 3744 & 3M/Centi \\ 3858 & 3M/Centi \\ 3858 & 3M/Centi \\ 3858 & 3M/Centi \\ 3874 & | S/N Membrane 3 3857 3M/Centi 3905 3M/Centi 3935 3M/Centi 3955 3M/Centi 4076 3M/Centi 4076 3M/Centi 3877 3M/Centi 3861 3M/Centi 4023 3M/Centi 3874 3M/Centi | S/N Membrane 3857 3MCenti 3905 3MCenti 3935 3MCenti 3935 3MCenti 3855 3MCenti 3877 3MCenti 4023 3MCenti 3874 3MCenti | 3857 3M/C 3905 3M/C 3905 3M/C 3935 3M/C 3935 3M/C 3955 3M/C 3955 3M/C 3861 3M/C 4023 3M/C 3874 3M/C | mbrane /Centi |
| Slot 1 Slot 2 Slot 3 Slot 4 Slot 5 Slot 6 Slot 7 Slot 8 | S/N Membrane 3318 Gore 3345 Gore 3340 Gore 3361 Gore 3361 Gore 3362 Gore 3363 Gore 3283 Gore 3283 Gore | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3320 Gore 3382 Gore 3382 Gore 3305 Gore 3283 Gore 3386 Gore 3386 Gore

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 | Membrane S 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 3 3M/Centi 5 3M/Centi 4 3M/Centi 3 3M/Centi | 3717
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3858 385 | S/N Membrane 3722 3M/Centi ⁵ 3877 3M/Centi ⁵ 3717 3M/Centi 3717 3M/Centi 3842 3M/Centi 3810 3M/Centi 3825 3M/Centi 3744 3M/Centi 3858 3M/Centi | S/N 3857 3877 3717 3842 3810 3861 3744 3858 3825 | Membrane 3M/Centi 3M/Centi 3M/Centi 3M/Centi 3M/Centi 3M/Centi 3M/Centi 3M/Centi 3M/Centi | 3857
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3874 | Membrane 3M/Centi | \$/N Membrane 3857 3M/Centi 3877 3M/Centi 3870 3M/Centi 3810 3M/Centi 3855 3M/Centi 4076 3M/Centi 3861 3M/Centi 3744 3M/Centi 3858 3M/Centi 3858 3M/Centi
 | S/N Membrane : 3857 3M/Centi 3905 3M/Centi 3935 3M/Centi 3955 3M/Centi 4076 3M/Centi 4076 3M/Centi 3861 3M/Centi 3861 3M/Centi 4023 3M/Centi | S/N Membrane 3 3857 3M/Centi 3905 3M/Centi 3905 3M/Centi 3935 3M/Centi 3844 3M/Centi 3955 3M/Centi 3877 3M/Centi 3861 3M/Centi 4023 3M/Centi | 3857 3M/C
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Slot 10 | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3320 Gore 3381 Gore 3382 Gore 3385 Gore 3283 Gore 3283 Gore 3261 Gore 3260 Gore | S/N Membrane 3318 Gore 3345 Gore 3345 Gore 3320 Gore 3361 Gore 3382 Gore 3305 Gore 3305 Gore 3283 Gore 3386 Gore 3261 Gore 3261 Gore

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386 | Membrane 7 3M/Centi 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 5 3M/Centi 5 3M/Centi 5 3M/Centi 6 3M/Centi 1 3M/Centi 1 3M/Centi 3 3M/Centi | S/N 371 387 372 384 381 382 374 385 386
 | Membrane S 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 2 3M/Centi 3 3M/Centi 4 3M/Centi 4 3M/Centi 3 3M/Centi 3 3M/Centi 3 3M/Centi 3 3M/Centi | 3717
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3863 | Membrane | Membra M | ne S/N Membrane i 3717 3M/Centi i 3877 3M/Centi i 3872 3M/Centi i 3822 3M/Centi i 3842 3M/Centi i 3840 3M/Centi i 3843 3M/Centi i 3825 3M/Centi i 3744 3M/Centi i 3858 3M/Centi i 3861 3M/Centi i 3863 3M/Centi | \$\frac{\text{S/N}}{3717} \frac{\text{Membrane}}{3717} \frac{3M/Centi}{3827} \frac{3M/Centi}{3722} \frac{3M/Centi}{3M/Centi} \frac{3842}{3M/Centi} \frac{3842}{3M/Centi} \frac{3810}{3825} \frac{3M/Centi}{3M/Centi} \frac{3825}{3M/Centi} \frac{3858}{3M/Centi} \frac{3M/Centi}{3861} \frac{3M/Centi}{3M/Centi} \frac{3863}{3M/Centi} | 3717 3M/Centi 3877 3M/Centi 3722 3M/Centi 3722 3M/Centi 3842 3M/Centi 3842 3M/Centi 3845 3M/Centi 3825 3M/Centi 3744 3M/Centi 3858 3M/Centi 3861 3M/Centi 3863 3M/Centi 3863 3M/Centi 3863 3M/Centi
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3842 | Membrane 3M/Centi | \$\text{S/N} & Membrane \\ 3857 & 3M/Centi \\ 3877 & 3M/Centi \\ 3810 & 3M/Centi \\ 3810 & 3M/Centi \\ 3855 & 3M/Centi \\ 4076 &
3M/Centi \\ 3861 & 3M/Centi \\ 3744 & 3M/Centi \\ 3874 & 3M/Centi \\ 3874 & 3M/Centi \\ 3842 & 3M/Centi \\ 3842 & 3M/Centi \\ 3842 \end{array} | S/N Membrane : 3857 3M/Centi 3905 3M/Centi 3935 3M/Centi 3935 3M/Centi 3955 3M/Centi 4076 3M/Centi 3871 3M/Centi 3861 3M/Centi 4023 3M/Centi 3874 3M/Centi 3475 3M/Centi | S/N Membrane 3 3857 3M/Centi 3905 3M/Centi 3905 3M/Centi 3935 3M/Centi 3844 3M/Centi 3955 3M/Centi 3857 3M/Centi 3861 3M/Centi 4023 3M/Centi 3874 3M/Centi 3475 3M/Centi | 3857 3M/C 3905 3M/C 3905 3M/C 3905 3M/C 3935 3M/C 3935 3M/C 3951 3M/C 3951 3M/C 3874 3M/C 3874 3M/C | mbrane /Centi |
| Slot 1 Slot 2 Slot 3 Slot 4 Slot 5 Slot 5 Slot 6 Slot 6 Slot 7 Slot 8 Slot 9 Slot 10 Subrack 5 | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3361 Gore 3382 Gore 3385 Gore 3263 Gore 3263 Gore 3263 Gore 3261 Gore 3261 Gore 3261 Gore 3260 Gore | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3381 Gore 3382 Gore 3385 Gore 3283 Gore 3286 Gore 3261 Gore April 17, 2003

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 | Membrane S 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 3 3M/Centi | 3717
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3863 | Membrane S/N | Membra M | ne S/N Membrane i 3717 3M/Centi i 3877 3M/Centi i 3877 3M/Centi i 3722 3M/Centi i 3842 3M/Centi i 3810 3M/Centi i 3810 3M/Centi i 3885 3M/Centi i 3888 3M/Centi i 3861 3M/Centi i 3863 3M/Centi September 10, 2003 | S/N Membrane 3717 3M/Centi 3877 3M/Centi 3877 3M/Centi 3722 3M/Centi 3842 3M/Centi 3810 3M/Centi 3825 3M/Centi 3744 3M/Centi 3861 3M/Centi 3861 3M/Centi 3863 3M/Centi 3863 3M/Centi 3863 3M/Centi 3864 3M/Centi 3865 3M/Centi 3867 3M/Centi 3868 3M/Centi 3868 3M/Centi 3869 3869 3M/Centi 3869 3M/Centi 3869 3M/Centi 3869 3M/Centi 3869 3869 3869 3869 3869 3869 3869 3869 38 | 3717 3M/Centi 3877 3M/Centi 3877 3M/Centi 3722 3M/Centi 3722 3M/Centi 3842 3M/Centi 3840 3M/Centi 3853 3M/Centi 3744 3M/Centi 3744 3M/Centi 3861 3M/Centi 3863 3M/Centi 3863 3M/Centi 3663 3M/Centi Cotober 15, 2003 | S/N Membrane 3722 3M/Centi 5 3877 3M/Centi 3871 3M/Centi 3842 3M/Centi 3840 3M/Centi 3825 3M/Centi 3744 3M/Centi 3858 3M/Centi 3861 3M/Centi 3863 3M/Centi 3863 3M/Centi December 9, 2003
 | S/N 3857 3877 3717 3842 3810 3861 3744 3858 3825 3863 | Membrane 3M/Centi | 3857
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 | S/N Membrane : 3857 3M/Centi 3905 3M/Centi 3935 3M/Centi 3955 3M/Centi 4076 3M/Centi 3877 3M/Centi 3861 3M/Centi 4023 3M/Centi 4023 3M/Centi 4023 3M/Centi 3874 3M/Centi 3475 3M/Centi | S/N Membrane 3 3857 3M/Centi 3905 3M/Centi 3905 3M/Centi 3935 3M/Centi 3935 3M/Centi 3877 3M/Centi 3877 3M/Centi 3861 3M/Centi 4023 3M/Centi 4023 3M/Centi 3475 3M/Centi 3475 3M/Centi | 6/N Mem 3857 3M/C 3905 3M/C 3905 3M/C 3844 3M/C 3955 3M/C 3861 3M/C 3871 3M/C 3871 3M/C 4023 3M/C 3874 3M/C 4023 3M/C 4023 3M/C 4023 1M/C 4023 1M/C 4024 1M/C 4025 1M/C 4026 1M/C 4027 1M | mbrane /Centi |
| Slot 1 Slot 2 Slot 3 Slot 4 Slot 5 Slot 6 Slot 7 Slot 8 Slot 9 Slot 10 Subrack 5 Slot | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3320 Gore 3361 Gore 3305 Gore 3283 Gore 3284 Gore 3261 Gore 3261 Gore 3260 Gore "Original" S/N Membrane | S/N Membrane 3318 Gore 3345 Gore 3345 Gore 3320 Gore 3361 Gore 3382 Gore 3305 Gore 3386 Gore 3283 Gore 3261 Gore 3261 Gore 3261 Gore 3261 Gore 3260 Gore 3260 Gore 3260 Gore Mpril 17, 2003 Membrane

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 | Membrane S 3M/Centi 73M/Centi 23M/Centi 23M/Centi 33M/Centi | 3717
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July | Membrane S/N | Membra M | ne S/N Membrane i 3717 3M/Centi i 3877 3M/Centi i 3877 3M/Centi i 3722 3M/Centi i 3842 3M/Centi i 3810 3M/Centi i 3810 3M/Centi i 3744 3M/Centi i 3744 3M/Centi i 3861 3M/Centi i 3863 3M/Centi i S863 3M/Centi i S964 3M/Centi | S/N Membrane 3717 3M/Centi 3877 3M/Centi 3877 3M/Centi 3722 3M/Centi 3842 3M/Centi 3842 3M/Centi 3825 3M/Centi 3825 3M/Centi 3858 3M/Centi 3861 3M/Centi 3863 3M/C | S/N Membrane 3717 3M/Centi 3877 3M/Centi 3873 3M/Centi 3722 3M/Centi 3842 3M/Centi 3840 3M/Centi 3855 3M/Centi 3744 3M/Centi 3858 3M/Centi 3861 3M/Centi 3863 3M/Centi 3863 3M/Centi 3863 3M/Centi 3863 3M/Centi Membrane Cotober 15, 2003 S/N Membrane | S/N Membrane 3722 3M/Centi 5 3877 3M/Centi 3717 3M/Centi 3717 3M/Centi 3842 3M/Centi 3825 3M/Centi 3825 3M/Centi 3744 3M/Centi 3858 3M/Centi 3861 3M/Centi 3863 | S/N 3857 3877 3717 3842 3810 3861 3744 3858 3825 3863 Decemb
 | Membrane 3M/Centi | 3857
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S/N | Membrane 3M/Centi 4, 2, 2004 Membrane | \$\frac{\text{S/N}}{\text{800}} \text{Membrane} \\ 3857 \\ 3M/\text{Centi} \\ 3871 \\ 3M/\text{Centi} \\ 3810 \\ 3M/\text{Centi} \\ 3855 \\ 3M/\text{Centi} \\ 3851 \\ 3M/\text{Centi} \\ 3861 \\ 3M/\text{Centi} \\ 3744 \\ 3M/\text{Centi} \\ 3858 \\ 3M/\text{Centi} \\ 3874 \\ 3M/\text{Centi} \ | S/N Membrane : | 3857 3M/Centi 3905 3M/Centi 3905 3M/Centi 3935 3M/Centi 3935 3M/Centi 3844 3M/Centi 3955 3M/Centi 3871 3M/Centi 3861 3M/Centi 4023 3M/Centi 3475 3M/Centi 3475 3M/Centi 3475 3M/Centi 3476 3476 3476 3476 3476 3476 3476 3476 3476 3476 3476 3476
 | Mem 3857 3M/C 3905 3M/C 3905 3M/C 3935 3M/C 3935 3M/C 3844 3M/C 3857 3M/C 3861 3M/C 3861 3M/C 3874 3M/C 3874 3M/C 3475 3M/C | mbrane //Centi |
| Slot 1 Slot 2 Slot 3 Slot 4 Slot 5 Slot 6 Slot 6 Slot 7 Slot 8 Slot 9 Slot 10 Subrack 5 Slot 5 Slot 1 | S/N Membrane 3318 Gore 3345 Gore 3340 Gore 3361 Gore 3361 Gore 3362 Gore 3365 Gore 3283 Gore 3283 Gore 3281 Gore 3261 Gore 3260 Gore "Original" S/N Membrane 3760 | S/N Membrane 3318 Gore 3345 Gore 3320 Gore 3381 Gore 3382 Gore 3305 Gore 3283 Gore 3261 Gore 3261 Gore 3260 Gore

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 | Membrane S 3M/Centi 23M/Centi 23M/Centi 23M/Centi 23M/Centi 33M/Centi 30M/Centi 30M/Centi | 3717
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 | Membrane 3M/Centi 4 3M/Centi 3M/Centi 4 3M/Centi | 3857
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386 | Membrane 7 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 2 3M/Centi 5 3M/Centi 5 3M/Centi 5 3M/Centi 1 3M/ | S/N 371 387 372 384 381 382 374 385 386 386 July S/N 338 325 | Membrane S 3M/Centi 7 3M/Centi 2 3M/Centi 2 3M/Centi 3 Gore 3 Gore | 3717
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5/N | Membrane S/N | Membra M | ne S/N Membrane i 3717 3M/Centi i 3877 3M/Centi i 3877 3M/Centi i 3722 3M/Centi i 3840 3M/Centi i 3841 3M/Centi i 3848 3M/Centi i 3861 3M/Centi i 3863 3M/Centi | S/N Membrane 3717 3M/Centi 3877 3M/Centi 3877 3M/Centi 3722 3M/Centi 3842 3M/Centi 3810 3M/Centi 3825 3M/Centi 3744 3M/Centi 3861 3M/Centi 3863 3M/Centi 3863 3M/Centi September 13, 2003 S/N Membrane 3867 3M/Centi 3848 3M/Centi 3872 3M/Centi 3874 3M/Centi 3872 3M/Centi 3874 3M | 3717 3M/Centi 3877 3M/Centi 3877 3M/Centi 3722 3M/Centi 3842 3M/Centi 3840 3M/Centi 3845 3M/Centi 3853 3M/Centi 3854 3M/Centi 3861 3M/Centi 3861 3M/Centi 3863 3M/Centi 3867 3M/Centi 3848 3 | S/N Membrane 3722 3M/Centi 5 3877 3M/Centi 3871 3M/Centi 3842 3M/Centi 3842 3M/Centi 3825 3M/Centi 3744 3M/Centi 3861 3M/Centi 3861 3M/Centi 3863 3M/Centi 5 5 5 5 5 5 5 5 5 | S/N 3857 3877 3717 3842 3810 3861 3744 3858 3825 3863 Decemb S/N 3867 3848 | Membrane 3M/Centi | S/N 3857 3877 3877 3863 3717 3861 3744 3858 3874 3842 January S/N 3867 3848 | Membrane 3M/Centi 4, 2, 2004 Membrane 3M/Centi 3M/Centi | \$\frac{\text{S/N}}{\text{Membrane}}\$ \text{3857} & \text{3M/Centi} \\ \text{3877} & \text{3M/Centi} \\ \text{3810} & \text{3M/Centi} \\ \text{3850} & \text{3M/Centi} \\ \text{3851} & \text{3M/Centi} \\ \text{3861} & \text{3M/Centi} \\ \text{3744} & \text{3M/Centi} \\ \text{3861} & \text{3M/Centi} \\ \text{3874} & \text{3M/Centi} \\ \text{3874} & \text{3M/Centi} \\ \text{3874} & \text{3M/Centi} \\ \text{3MN} & \text{Membrane} \\ \text{3MN/Centi} \\ \text{3M/Centi} \ | S/N Membrane 3857 3M/Centi 3905 3M/Centi 3935 3M/Centi 3955 3M/Centi 4976 3M/Centi 4976 3M/Centi 3877 3M/Centi 3861 3M/Centi 4023 3M/Centi 3475 3M/Centi 3475 3M/Centi 5476 3M/Centi 5476 3M/Centi 3873 3M/Centi 5476 3M/Centi 3873 3M/Centi 3867 3M/Centi 3590 3M/Centi 3590 3M/Centi 3590 3M/Centi 3590 3M/Centi 3673 3M/Centi 3590 3M/Centi 3687 3M/Centi 3590 3M/Centi 3687 3M/Centi 3687 3M/Centi 3687 3M/Centi 3687 3M/Centi 3687 3M/Centi 3680 3M/Centi 3687 3M/Centi 3680 3M/C | S/N Membrane 3857 3MCenti 3905 3MCenti 3935 3MCenti 3935 3MCenti 3844 3MCenti 3855 3MCenti 3861 3MCenti 4023 3MCenti 3475 3MCenti 3475 3MCenti S/N Membrane 3867 3M/Centi 3590 3M/Centi 3590 3M/Centi | Mem 3857 3M/C 3905 3M/C 3905 3M/C 3935 3M/C 3935 3M/C 3844 3M/C 3861 3M/C 3877 3M/C 3874 3M/C 3475 3M/C | mbrane //Centi |
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3M/Centi 4072 3M/Centi 4074 3M/Centi 4074 3M/Centi 4075 4	Section Sect	mbrane //Centi

Cartridge Removed

Notes: New Cartridge

a Discovered large leak on next service call. Cartridge replaced at next service call.
b Repeated cartridge trips. Cartridge replaced at next service call.
c Loose cover screws. Re-torque cover screws and place in back-up cartridge inventory.
d Cover cracked. Replaced at next service call.
c Cartridges running since April 17 in SR1. Suspected leaking, but tested and passed at Avista Labs.
Lab tests revealed high impedence to LL MEA. Suspect cell reversal damage due to membrane flooding or water blockage of gas flow passages.